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RESEARCH ARTICLE

An Ingenious Technique to Track the Maximum Power Point for a Wind Energy System

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ABSTRACT The conventional techniques employed for tracking maximum power suffer from several issues. The perturb and observe (P&O) algorithm is extremely popular among the conventional techniques for WECS to track and capture the maximum power point. The major issue with this algorithm is opting for an appropriate step size. A new technique is developed and described in this paper, which combines the trapezoidal rule and the fuzzy logic control technique, to address this issue. Two techniques are compared with the proposed algorithm: the trapezoidal rule-based P&O (TRPO) algorithm and the conventional P&O method to prove the superiority of the technique presented in this work. MATLAB/Simulink simulation showcases the enhancement of power by this technique. Randomly varying wind speeds were used to examine the power output of all three algorithms. The results obtained after simulation portray significant enhancement in DC output current, voltage, and power with considerable reduction in the oscillations by employing the proposed technique.

INDEX TERMS Wind energy, wind energy conversion systems, maximum power point tracking, green energy.

I. INTRODUCTION

Enormous industrial growth with higher standards of living and a manifold increase in the population has resulted in the increased need for energy. There is a significant increase in global energy demand and consumption, which has resulted in a decline in conventional resources like oil, gas, coal, etc. Therefore, the popularity and use of renewable resources are increasing as they are environment-friendly and can fulfill energy needs, giving a safer future. Wind energy is being preferably adopted for obtaining usable power as it is an excellent clean energy resource [1].

The objective behind using the wind energy conversion system (WECS) is to provide electrical energy obtained by employing the wind turbine (WT) together with the electrical power conversion systems. The only issue with wind as a resource is that it fluctuates too much, so it becomes difficult to capture maximum energy from the wind turbine (WT). The WT is basically employed for the conversion and capture of the power available in the wind. The essential components of the WECS can be seen in Figure 1.

The blades facilitate the conversion from mechanical to electrical energy along with the generator stage employed. Among the types of generators used in WECS are Squirrel cage induction generators (SCIG) that exhibit advantages such as lower cost, complexity, and greater reliability. Another economical option in place of SCIG is a doubly fed induction generator (DFIG) when used with converters. Excitation and multi-stage gearbox requirements are the main drawbacks of DFIG [2], [3], [4]. The wide use and popularity

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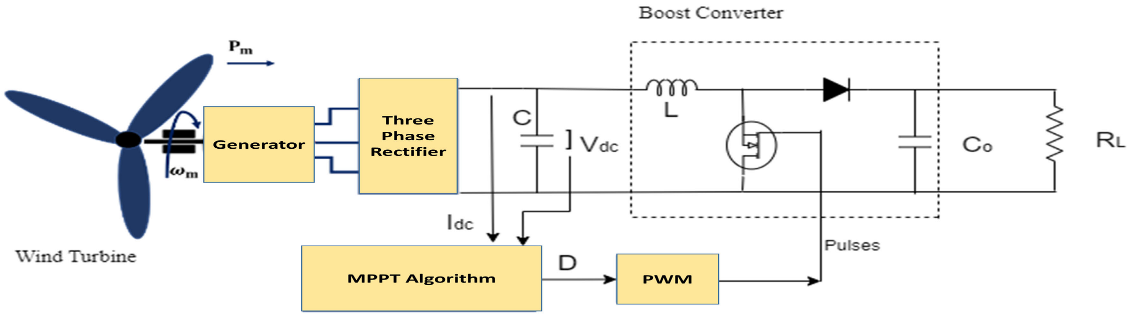


FIGURE 1. Wind power system.

TABLE 1. Nomenclature.

Abbreviation	Full form
WT	Wind Turbine
WECS	Wind energy conversion system
MPP	Maximum power point
MPPT	Maximum power point tracking
PO	Perturb and observe
CPO	Conventional perturb and observe
SCIG	Squirrel cage induction generator
DFIG	Doubly fed induction generator
PMSG	Permanent magnet synchronous generator
IPC	Indirect power control
DPC	Direct power control
TSR	Tip speed ratio
TRPO	Trapezoidal rule based PO
PSF	Power signal flow
OT	Optimal torque
INC	Incremental conductance
ORB	Optimal relation based
NN	Neural network
ANN	Artificial neural network
ACO	Ant colony optimization
FLC	Fuzzy logic control
FIS	Fuzzy Inference System
MPO	Modified perturb and observe
PSO	Particle swarm optimization
PWM	Pulse width modulation

of Permanent magnet synchronous generators (PMSGs) are evident as they exhibit the advantages of being cheap, reliable, and present self-excited nature [5], [6].

A. NOMENCLATURE

A list of the abbreviations used in this manuscript is given below in Table 1.

Generators are comprehensively reviewed in [7], [8], and [3]. Power converters employing three-phase rectifiers using DC/DC converters are preferable for stand-alone wind power systems as these are cheap and reasonably reliable [9]. The yielded power is immensely impacted by the wind variations. The efficient tracking and extraction take place only if the highest power at every single wind speed is tracked and extracted. This phenomenon of capturing power is efficiently carried out with the help of a maximum power point tracking (MPPT) algorithm. The MPPT algorithms play a phenomenal part in the efficient tracking of maximum power for WECS. In the reviewed literature, it is evident that the MPPT techniques for WECS can be grouped into three types. The first type uses the information of the WT characteristics, whereas in the second type, it is not required, and the third is a combination of the first two [10]. The techniques, optimal torque control (OTC), tip speed ratio (TSR), and power signal feedback (PSF) are the conventional methods. In these techniques, the knowledge of the speed of the wind, the angular speed of the shaft of the generator, and the WT characteristics are utilized by the TSR [11], [12] and PSF [13] methods, whereas the knowledge of the speed of the wind is not required however the WT parameter knowledge is needed. The disadvantages of the first type of MPPT techniques include the requirement of the sensors and the information of the accurate parameters of the WT, which are practically difficult to establish. The second type of MPPT technique is relatively simple, as there is no requirement for either wind speed estimation or WT characteristics. The algorithm, Perturb and observe (P&O), falls under this type [14]. All the conventional MPPT techniques are included in the DPC and IPC-based techniques. Incremental conductance (INC) [15], optimal relation-based (ORB) [16] and perturb and observe (P&O) [17] techniques belong to the DPC type.

The P&O technique is immensely preferred since it is simple to implement, and there is no speed sensor requirement. However, this technique suffers from the disadvantage that the employment of the suitable step size is a difficult task while extracting the optimal power from WECS [18], [19], [20], [21]. For larger dimensions of the employed steps, the MPP converges faster, but oscillation around the MPP is observed in this scenario. Conversely, if the steps used are smaller, then the convergence with the MPP takes too long or, at times, doesn't happen. The third kind of the MPPT technique is derived by merging the first two methods [10], [22].

The MPPT techniques are comprehensively reviewed in [23], where all three types and the recently used methods for MPPT techniques are categorized and reviewed. Apart from the P&O technique, conventionally used MPPT methods suffer from some kinds of issues. Different modifications have been carried out in the conventional P&O (CPO) method by merging it with soft computing methods, and a hybrid version is available to overcome the issues encountered in the conventional methods. The method adopted in [24] uses the PSF method along with the modified P&O (MPO) to eliminate the drawback of incorrect direction during high wind speed variations. The method adopted in [25] is capable of eliminating the CPO drawbacks by merging CPO and ORB. The work in [26] overcomes the CPO issues by employing MPO articulated by the modular sector approach. The model reference adaptive technique is used in combination with varying step sizes to eliminate the CPO issues in [26]. The approach of adaptive step-based MPO is used in [27] and [28], but it presents a significant computational burden. The MPO technique in [27], [29], and [30] needs sensors and exhibits higher transient overshoot. It is evident from the literature that each conventional method displays its own benefits and demerits. To benefit from the merits of these methods and eliminate the associated issues, two or more methods are merged, and a new hybrid method that improves the performance is obtained. The issues of the conventional techniques are overcome using hybrid methods. It is evident from the reviewed literature that intelligent techniques have been useful in overcoming the issues occurring with conventional techniques. Intelligent techniques like Fuzzy logic control (FLC) are found to be used in the literature [31] to overcome the issues associated with conventional methods like P&O. The work presented in [32] employs a model predictive control technique using FLC to track MPP. The work done in [33] presents an adaptive FLC technique for tracking the MPP. A comparison of CPO and FLC is presented in [34]. FLC-based MPPT is used in [35] to overcome the issues of the CPO technique. The work presented in [36] employs FLC that uses the change in the output power and the change in the rotational speed as inputs to the FLC. This method, however, requires sensors to estimate the speed. The FLC approach presented in [37] very well addresses the issue of tracking speed and efficiency trade-off that occurs in CPO. Some advanced soft computing methods like neural networks (NN) and artificial neural networks (ANN) have also been found to be used to eliminate the issues of conventional techniques. Artificial intelligence (AI) based MPPT techniques are trending, and NN and ANN-based algorithms have been reviewed in [23]. However, their implementation is practically difficult and costly, increasing the computational burden.

In the recent works, different meta-heuristic techniques are found to be employed like ant colony optimization (ACO) used in [38], particle swarm optimization (PSO) employed in [39], and grey wolf optimization (GWO) used in [40] to implementing the MPPT algorithms. The main drawback of these techniques is that the computational complexity is higher, as a large number of iterations are required while tracking the maximum power point (MPP), and power fluctuations may occur due to the random search technique.

It is evident that a criterion of performance can be improved at the cost of the other criterion in the existing algorithms presented for tracking the MPP. The most challenging task is capturing the maximum power under high wind fluctuations with the help of the MPPT technique with minimum computational burden and oscillations around the MPP. There is a requirement for simple methods for this purpose. Numerical methods have provided simple solutions to various issues in mathematics, engineering, computer science, and other related areas. The technique presented in [41] and [42] uses the trapezoidal rule with CPO to track the MPP for a solar photovoltaic system. The work in [43] has presented a three-step procedure: a P&O-based MPPT method for WECS using the trapezoidal rule (TRPO). The maximum values of power and reference voltage obtained after the application of the trapezoidal rule are passed on to further apply CPO to get the duty cycle, which is employed to track the MPP. Thus, the CPO method is merged with the trapezoidal rule in TRPO. It still suffers from the issues of CPO selecting an appropriate step size for tracking the MPP.

In this work, the trapezoidal rule is used with the FLC technique to capture maximum output power. The rectified voltage and current are fed as the inputs to the MPPT technique. The trapezoidal rule is applied to extract the maximum values of power and voltage, and these are then passed on to apply FLC in order to provide the duty cycle to track the MPP. This combination helps to overcome the issue of selecting the step associated with TRPO.

The rest of this work is organized as follows: The description of the related concepts is provided in section II. The simulation details of the algorithm proposed are described in section III, followed by the simulation results given in the fourth section. Discussions and conclusions are presented in the end.

II. RELATED CONCEPTS

The block diagram representation of the wind power system is shown in Figure1. As depicted in Figure1, the WT captures the power available in the wind, and only 59% is extracted out of the energy possessed by the wind according to the Betz limit. The extracted mechanical power from WT is P_m which is given in Equation (1). P_{air} is the power contained in the air, which is given by the expression (2), where ρ is the density of air, wind velocity in m/s is represented by V and A is the swept area covered by the blades of the turbine given in m^2. In expression 3, angular velocity in rad/sec is ω, λ is TSR, and the radius is given as R. C_p which is the power coefficient

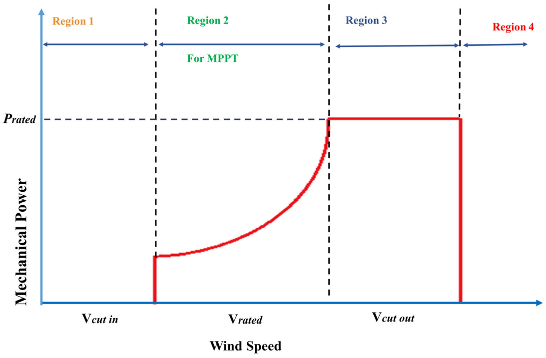


FIGURE 2. WECS operating regions [44].

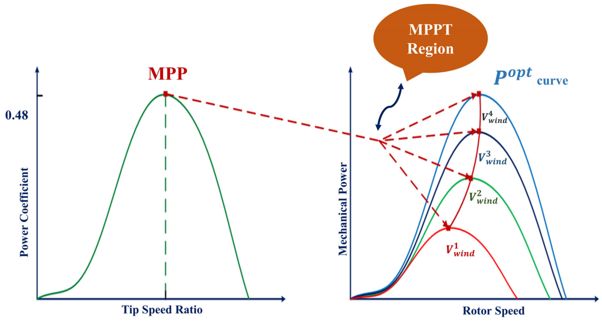


FIGURE 3. WT characteristics for λ opt and C_{popt}. [44].

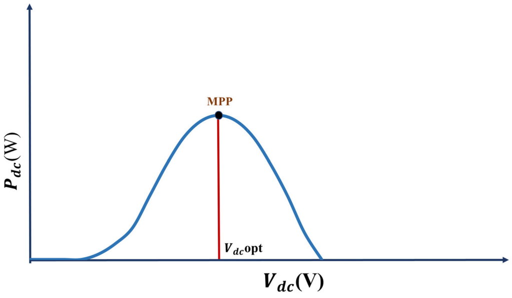


FIGURE 4. Relation between V_{dc} and P_{dc}.

depicted in expression (4) has a value restricted below 59%, P_{air} is the contained power in the wind and power absorbed by the WT is $P_{windturbine}$. The four Equations 1 2, 3 and 4 are as given in [26].

The WT provides input to the generator stage that facilitates the conversion of energy from the mechanical to electrical form. The three-phase supply from the generator is given to the three-phase rectifier for DC conversion. The boost converter stage facilitates the DC-DC boost conversion, which is controlled by the MPPT algorithm. The duty cycle generated by the employed algorithm is fed to the pulse width modulation (PWM) generator, which controls the switching element, thereby boosting the voltage and, hence, the power. Figure 2 shows the various regions of the output power for WECS. The first region depicts the region where the WT cannot produce any power because of the very low speed of the wind. The region between the cutin and the rated wind speed is of extreme importance pertaining to the control aspect for extracting maximum power from the WECS. In the third region, the system is protected as the speed of the wind lies between the rated and the cutout values. The fourth and last region corresponds to the region having wind speeds higher than the cutout values.

$$P_m = \frac{1}{2}\rho A V^3 C_p(\lambda, \beta) \tag{1}$$

$$Pair = \frac{1}{2}\rho A V^3 \tag{2}$$

$$\lambda = \frac{R * \omega}{V} \tag{3}$$

$$C_p = \frac{P_{windturbine}}{P_{air}} \tag{4}$$

This work focuses mainly on the second operating region in which the MPPT technique is employed to obtain maximum power from WECS. Figure 3 clearly depicts the principle of MPPT for WECS. When the WECS operation takes place at the optimum power curve, maximum power can be extracted. The operation of the WECS at this curve is facilitated by the MPPT algorithm. Thus, the MPPT algorithm aids in the capture and tracking of maximum output power for WECS.

A. PROPOSED MPPT TECHNIQUE

The CPO technique involves scanning the previous and current values of rectified voltage to track the MPP, so choosing the appropriate step is crucial to avoid oscillations around the MPP and achieve faster tracking. It is observed that there is a trade-off between the two. This issue is addressed by the proposed technique. Figure 4 depicts the relation between V_{dc} and P_{dc} [37] and also gives the selection for the step size for CPO. For an optimal value of V_{dc}, a maximum P_{dc} (MPP) is achieved.

This relation is utilized to develop the proposed technique. Figure 6 shows the three phases in which the proposed technique works. In the first phase, the trapezoidal rule is employed to divide the V_{dc}-P_{dc} plot into equal-width trapezoids. The second phase involves the comparison of the previous and current trapezoids to obtain the values of maximum area and power. This theme is depicted in Figure 7. In the third phase, these values are passed on to implement the FLC to track the MPP.

The basic FLC framework can be seen in Figure 8. P_{out} and V_{out} are the values given out after the trapezoidal rule is applied. These values are further passed on to the FLC. The ratio of δP and δV obtained as in Equation 5 and 6 are used to obtain the inputs error denoted by ‘e’ and change in error denoted by ‘ec’ respectively. Equation 7, Equation 8, and Equation 9 respectively specify the FLC inputs ‘e’ and ‘ec’. The FIS type employed is Mamdani, and the defuzzification method used is centroid. Minimum (min) and Maximum (max) are the implication and aggregation methods defined,

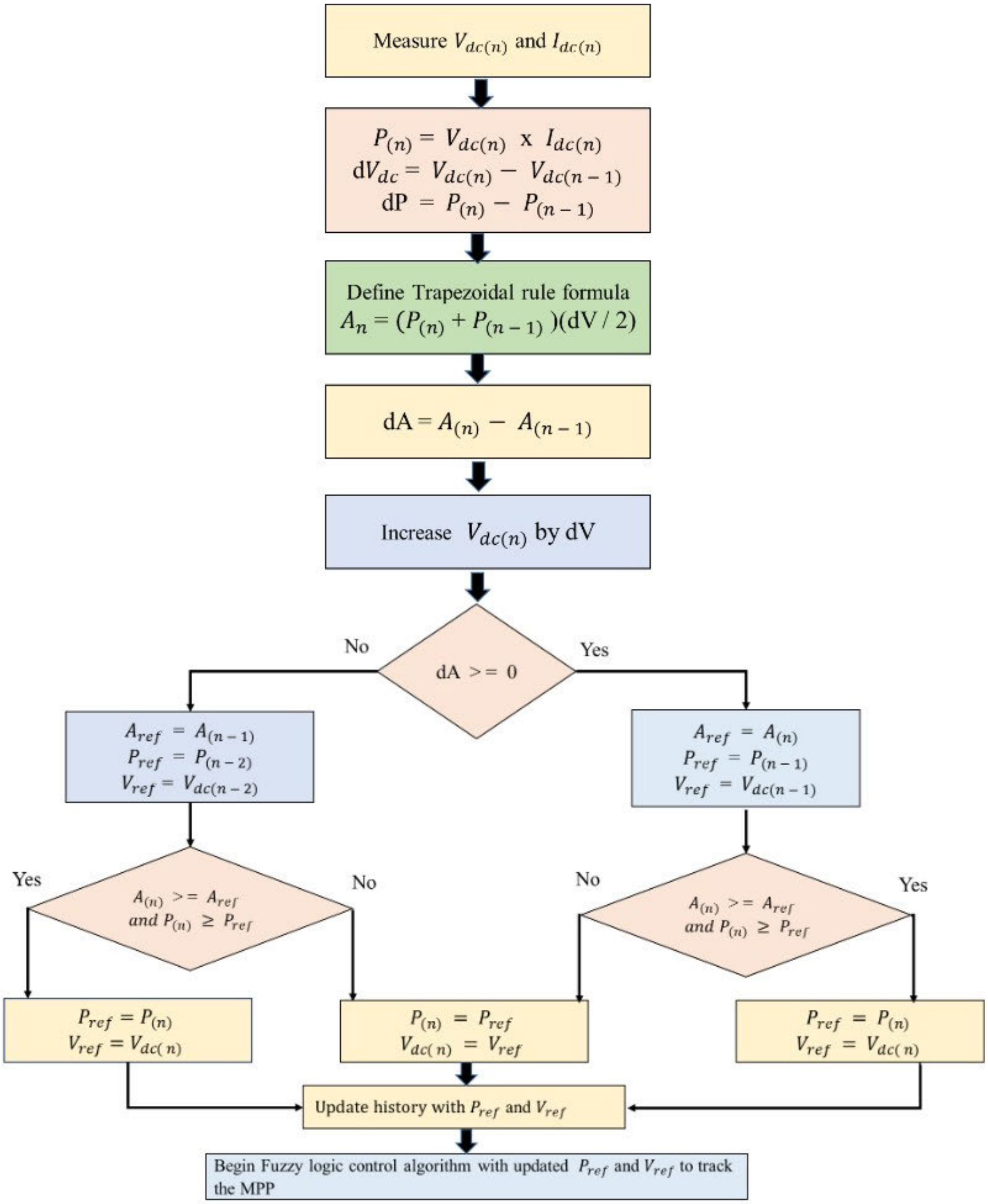


FIGURE 5. Procedure of the proposed MPPT method.

respectively. FLC is capable of tracking the changes in the speed of the wind precisely. The controller receives the inputs 'e' and 'ec', which undergo fuzzification to produce the fuzzy set. The inference system processes the fuzzy set with the help of the fuzzy rules in order to provide the appropriate fuzzy output. The fuzzy output is finally converted to the duty cycle after defuzzification, which is used further to control the switching element of the boost converter and facilitate MPP tracking.

$$\delta P = P_{(n)} - P_{(n-1)} \tag{5}$$

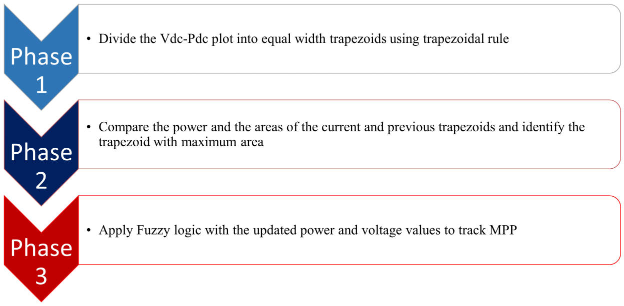
$$\delta V = V_{(n)} - V_{(n-1)} \tag{6}$$

$$e_{(n)} = \delta P / \delta V \tag{7}$$

$$e = e_{(n)} \tag{8}$$

$$ec = e_{(n)} - e_{(n-1)} \tag{9}$$

Figure 9, 10 and 11 show the membership function for the inputs 'e', 'ec' and D. Seven variables Nbig, Nmed, Nsmall, Zero, Psmall, Pmed, Pbig are defined for these membership functions. The detailed logic behind the fuzzy rules can be given as:



- Divide the Vdc-Pdc plot into equal width trapezoids using trapezoidal rule
- Compare the power and the areas of the current and previous trapezoids and identify the trapezoid with maximum area
- Apply Fuzzy logic with the updated power and voltage values to track MPP

FIGURE 6. Phases of the proposed technique.

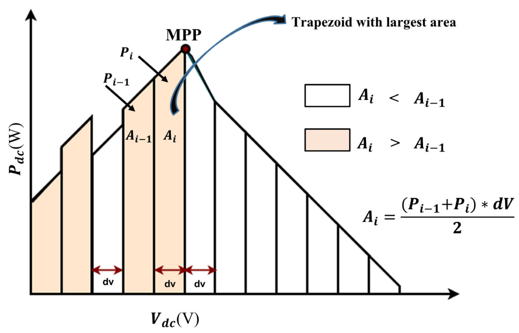


FIGURE 7. Theme of the proposed technique.

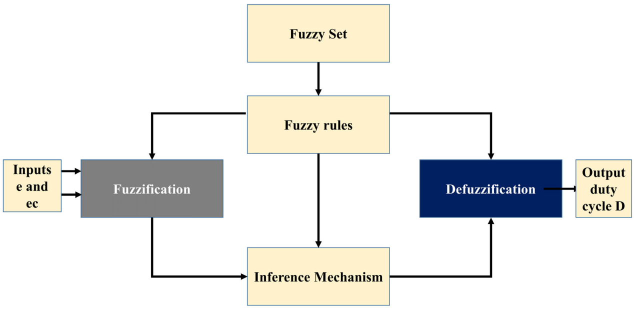


FIGURE 8. Basic frame work of FLC.

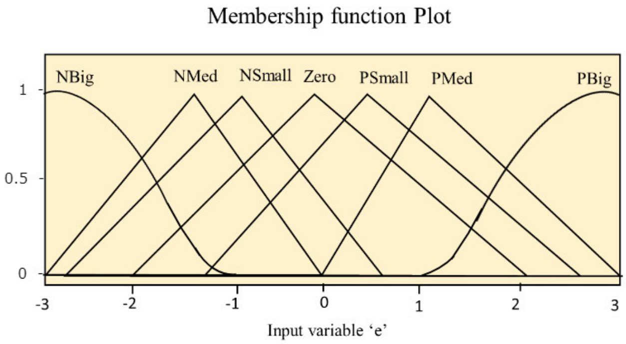


FIGURE 9. FLC input e membership function.

If e = NBig and ec = NBig then D = Zero;
If e = NBig and ec = NMed then D = Zero;
If e = NBig and ec = NSmall then D = Zero;

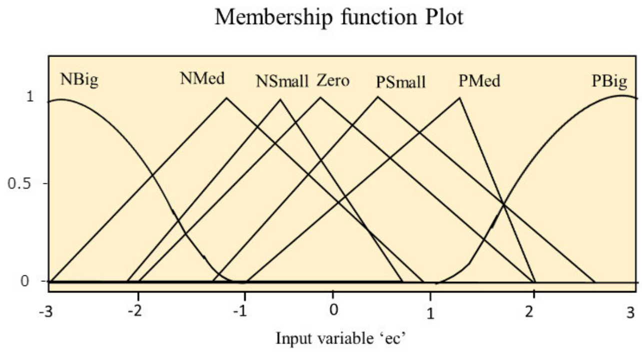


FIGURE 10. FLC input ec membership function.

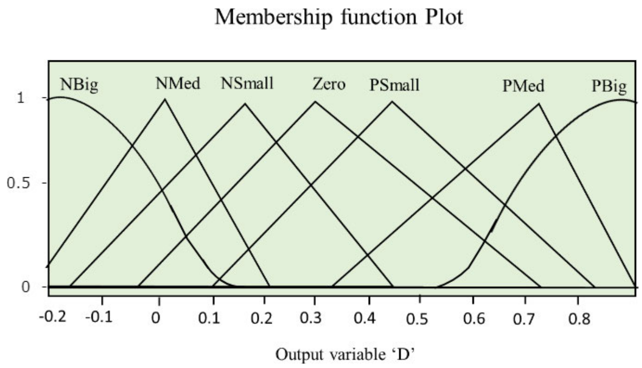


FIGURE 11. FLC output D membership function.

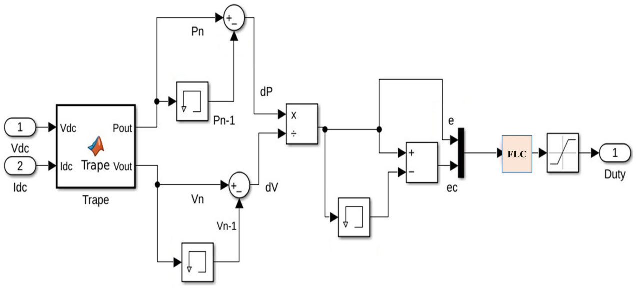


FIGURE 12. Fuzzy logic applied after trapezoidal rule in the proposed algorithm.

The 49 rules that are framed for FLC are shown in Table 2. The block diagram for FLC used during simulation is shown in Figure 12. The detailed procedure is depicted in Figure 5.

III. SIMULATION OF THE CPO AND THE PROPOSED TECHNIQUE

Figure 13 shows the WECS model with the blocks of TRPO, CPO, and the proposed trapezoidal rule-based FLC MPPT techniques that are simulated in MATLAB/Simulink. A manual switch is used in the WECS to simulate one technique at a time. Table 3 presents the parameters of the simulated system. Figure 14 shows the CPO block in Simulink. Figure 15 shows the Simulink model for the TRPO method, and Figure 16 depicts the blocks for the technique

TABLE 2. Rules for FLC.

Output D	Input 'e'							
Input 'ec'		NBig	NMed	NSmall	Zero	PSmall	PMed	PBig
	NBig	Zero	Zero	NSmall	NMed	PSmall	PMed	PBig
	NMed	Zero	Zero	Zero	NSmall	PMed	PMed	PBig
	NSmall	Zero	Zero	Zero	Zero	PMed	PMed	PBig
	Zero	NBig	NSmall	Zero	Zero	PSmall	Zero	Zero
	PSmall	NBig	NMed	NSmall	Zero	Zero	Zero	Zero
	NMed	NBig	NMed	NSmall	PSmall	Zero	Zero	Zero
	PBig	NMed	NMed	NSmall	PMed	Zero	Zero	Zero

TABLE 3. Simulation system parameters.

WT Parameters	Value and unit
Radius	3.01m
Air density	1.22kg/m^3
Rated Power	1 Kilo Watt
β	0
PMSG Parameters	Value and unit
Rated Power	1 Kilo Watt
Pole pairs	2
Rs	1.6 Ω
Ld=Lq	6.3 miliHenry
J	8.54 kgm^2
Boost converter Parameters	Value and unit
L	75 miliHenry
C	0.468 μFarads
Switching frequency	5KHz
RL	54 Ω

TABLE 4. Comparison of the rise time. response time and the transient time of all the three simulated techniques.

Name of the MPPT algorithm	Rise time (m sec)	Transient time (m sec)	Response time (m sec)
Trapezoidal rule based Fuzzy logic	0.1231	6.9450	0.035
Trapezoidal rule based PO	0.2133	6.9450	0.040
Conventional P&O	0.3200	6.9700	0.060

TABLE 5. Comparison of the tracking efficiency for all the three techniques at the rated wind speed of 5 m/s.

Name of the MPPT algorithm	MPPTracking efficiency
Trapezoidal rule based Fuzzy logic	99.1%
Trapezoidal rule based P&O	92.7%
Conventional P&O	87%

proposed. Figure 17 depicts the power coefficient for all three techniques. Figure 18 depicts the random variation in the wind speed used during the simulation of all three techniques. The curve in red is for the proposed technique, light blue for TRPO, and navy blue for the CPO method. Figures 19, 20, and 21 show the comparative voltage, current, and DC output power respectively achieved with all three techniques. The markings A, B, C, D, and E on these figures depict the reduction in oscillations and enhanced output power, voltage, and current. It is evident from these figures that the proposed technique contributes to reducing the oscillations and enhancing the power yielded at the output.

IV. RESULTS

The previous section describes the simulation of the TRPO, CPO, and the technique proposed in MATLAB/Simulink. Figure 17 portrays the power coefficient for all three techniques. The details of the specifications of the system simulated are given in Table 3. The variations in the speed of the wind are as in Figure 18. The graphs plotted in Figure 19, 20, and Figure 21 indicate higher yielded voltage, current, and power, respectively. The comparison of the technique proposed with the other two proves the superiority of the algorithm proposed. The sections A, B, C, and D in these figures indicate reduced oscillations and higher power yielded at the output. The variation in the wind speed was done randomly from 4, 5, 4, 3, and 5 m/sec for all three methods. For all the techniques, the maximum simulated power output is yielded at the rated wind speed of 5m/s. The maximum values of the duty cycle for the proposed, TRPO and CPO methods are 0.37, 0.302, and 0.29, respectively. Table 4 depicts the comparison of the rise time, response time, and transient time of all three simulated methods. It is evident from the comparison presented in Table 4 that the presented technique provides a faster response in tracking the MPP. Table 5 shows that the tracking efficiency of the proposed technique while tracking the MPP is maximum among all three techniques; the comparison with the previous works shown in Table 6 indicates the superiority of the proposed technique. There is a 0.6%, 6.8%, and 1.06% enhancement obtained in voltage, current, and power, respectively, at the output with the adoption of the TRPO method compared to CPO. Power is further

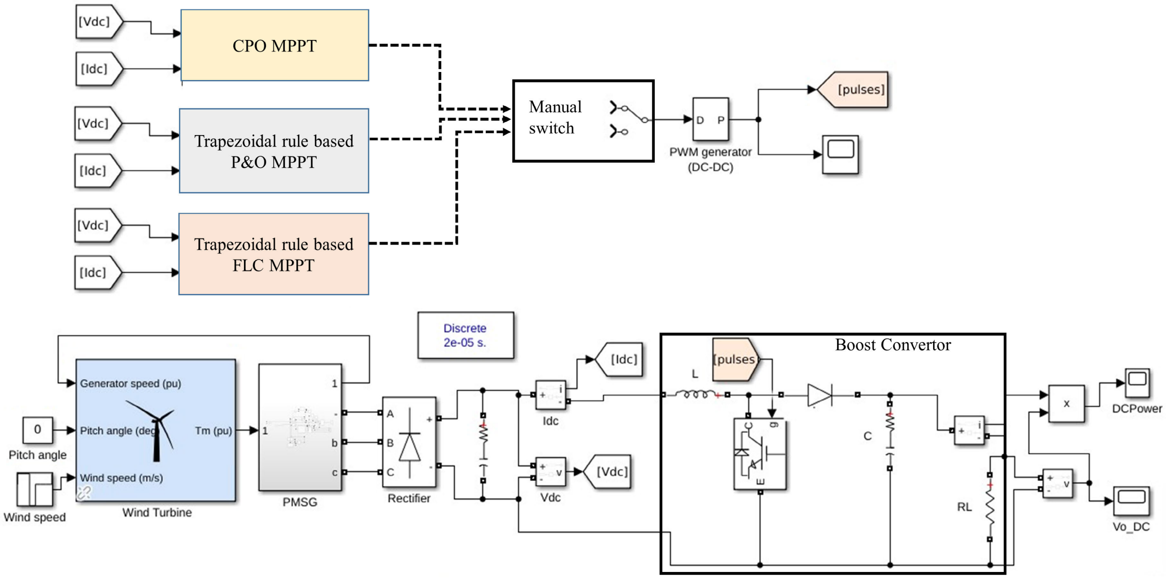


FIGURE 13. Simulation Model in MATLAB/Simulink for the TRPO, CPO and the proposed algorithm.

TABLE 6. Comparison of the MPPT techniques.

Parameters of the MPPT technique	TSR [15], [45]–[48]	PSF [15], [45], [46]	OT [15], [45]–[48]	CPO [15], [45]–[48]	INC [15], [45]–[48]	ORB [15], [45]–[48]	NN [45], [47]	TRPO [43]	Proposed Technique
Efficiency of Tracking MPP	High	Moderate	Moderate	Low	Low	Moderate	High	High	High
Convergence speed	High	High	High	Low	Low	Medium	High	High	High
Oscillations near the MPP	No	No	No	Yes	Yes	No	No	No	No
Training data requirement	No	Yes	Yes	No	No	No	Yes	No	No
Wind speed estimation sensor requirement	Yes	Yes	No	No	No	No	Depends	No	No
Performance under changing wind speed	High	Moderate	High	Moderate	Moderate	Moderate	High	High	Excellent

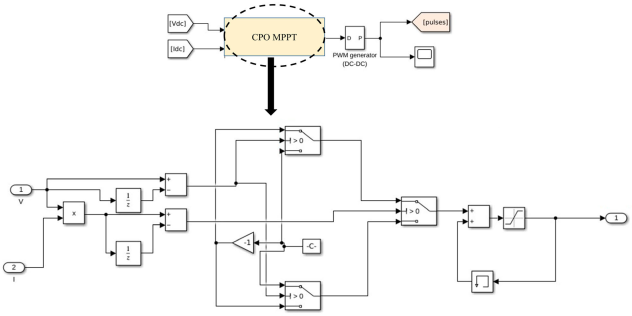


FIGURE 14. CPO technique SIMULINK block.

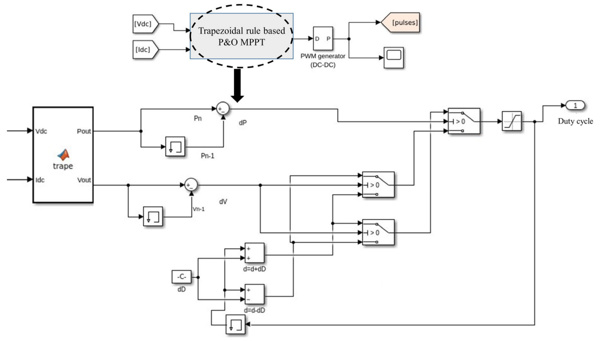


FIGURE 15. SIMULINK block for TRPO algorithm.

enhanced with the help of the proposed Trapezoidal rule based FLC technique as it presents 8.02% enhancement in the DC output power, 6.14% enhancement in the DC output voltage, and 6.14% enhancement in the DC output current as compared to CPO. The proposed technique (Trapezoidal based FLC technique) yields 5.4%, 5.4%, and 7.36% more output DC voltage, current, and power, respectively, than the TRPO technique. The superiority of the proposed technique while tracking the MPP helps yield maximum extracted power.

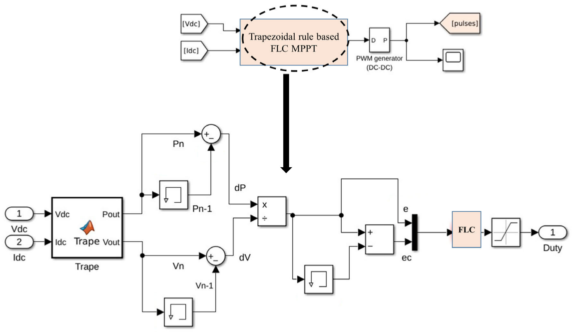


FIGURE 16. Simulation block for the presented technique in MATLAB/Simulink.

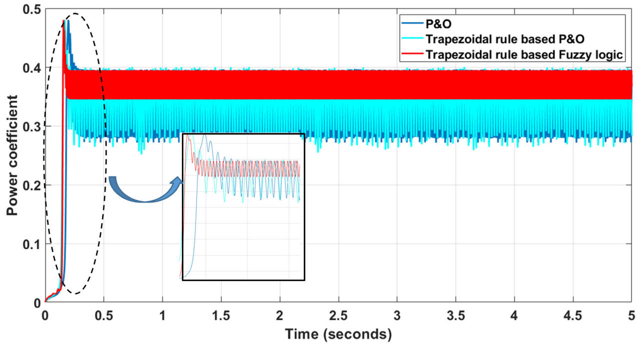


FIGURE 17. Plot of the Power coefficient.

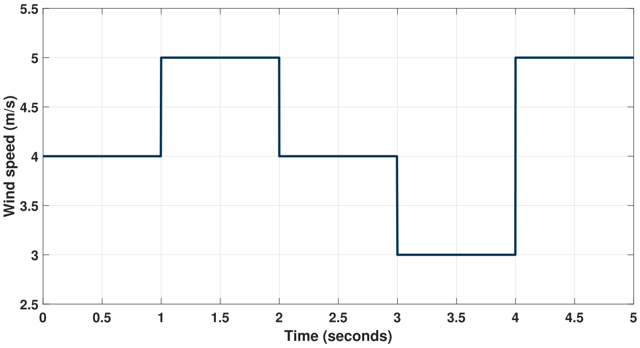


FIGURE 18. Profile of variation in the wind speed.

V. DISCUSSION

A large variety of MPPT methods for WECS are available in the literature. A parameter of performance can be improved at the cost of the other in the existing methods presented for tracking the MPP. The most challenging task is to yield maximum power with the help of the MPPT technique with minimum computational burden and oscillations around MPP and improve the system performance for highly fluctuating wind conditions. Optimization techniques based on MPPT are quite evident, but they appear to suffer from problems like a higher computational burden for MPP tracking. The recent hybrid methods available can eliminate the issues of conventional techniques but are found to be complex during the implementation process. There is a requirement for simple methods for this purpose. Numerical methods have been providing simple solutions to a variety of issues in mathematics, engineering, computer science, and other related areas. When they are merged with existing methods, the MPP for WECS can be tracked efficiently. The approach adopted in the presented work is based on the trapezoidal rule merged with the FLC method. The MPP tracking process does not require speed sensors, and a reduction in oscillations with enhanced power is achieved by the proposed technique. Future research can be based on merging numerical methods and several existing approaches to further enhance system performance and obtain quicker tracking and improved power extraction from WECS.

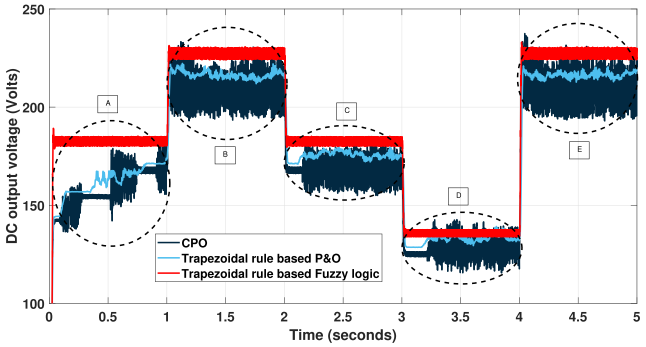


FIGURE 19. Plot of Time and output Voltage.

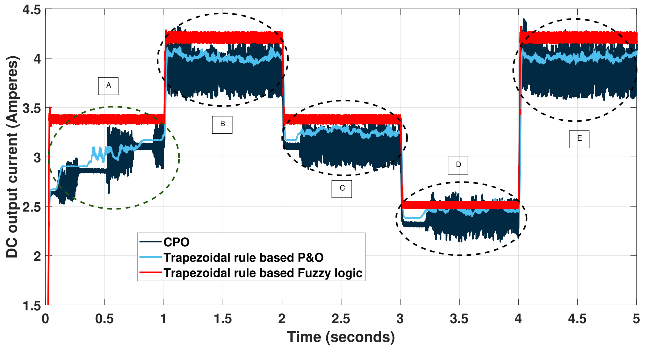


FIGURE 20. Plot of Time and output Current.

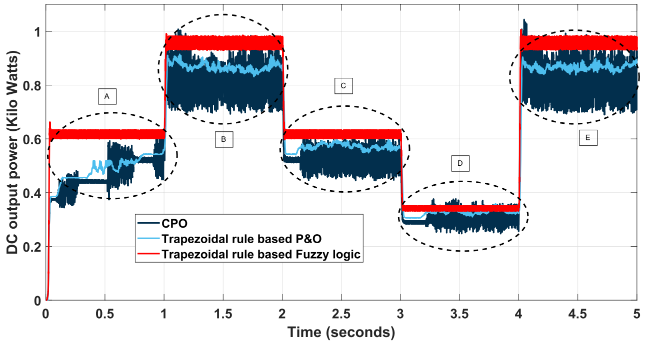


FIGURE 21. Plot of Time and output Power.

VI. CONCLUSION

The existing scenario of MPPT algorithms for WECS depicts immense variations in the approaches adopted for tracking the MPP, ranging from conventional techniques to advanced soft computing and optimization-based strategies. The recent techniques efficiently track the MPP but suffer from issues like higher complexity of implementation. Simpler tracking methods are therefore needed. The earlier works also present the combination of numerical methods like the trapezoidal rule and conventional approaches like the CPO. The approach in this presented work employs a combined technique, which is a trapezoidal rule-based FLC technique for tracking the MPP for WECS. The procedure adopted for this technique is carried out in three phases. In the first phase, the V_{dc}-P_{dc} curve is divided into trapezoids having the same width using the trapezoidal rule. The second phase involves identifying the largest trapezoid possessing maximum power. The third phase involves the application of fuzzy logic control (FLC) to track the MPP using the power and voltage values of the identified trapezoid. There is no wind speed sensor requirement for implementing the presented technique. The superiority of this approach is proved after comparing it with the CPO method and the TRPO technique in simulation and the existing techniques in the literature. The variation in the wind speed was done randomly from 4, 5, 4, 3, and 5 m/sec for all three methods. For all the techniques, the maximum simulated power output is yielded at a rated wind speed of 5m/s. There is a 0.6%, 6.8%, and 1% enhancement in the output voltage, current, and power, respectively, with the adoption of the TRPO method compared to CPO. The power is further enhanced with the help of the proposed Trapezoidal based FLC technique as it presents 8.02% enhancement in the DC output power, 6.14% enhancement in the DC output voltage, and 6.14% enhancement in the DC output current as compared to CPO. The proposed technique (Trapezoidal rule based FLC technique) yields 5.4%, 5.4%, and 7.36% more output DC voltage, current, and power, respectively, than the TRPO method. The graphs plotted indicate significant power enhancement by adopting the presented approach. The higher tracking efficiency of the proposed technique helps to track and yield maximum power. Future directions can be around the combination of hybrid, intelligent, conventional techniques and numerical methods to obtain simple methods for faster tracking of MPP with enhanced extracted power for WECS.

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